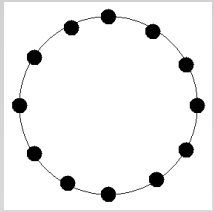
Synchronization and Extreme Fluctuations in Small-World-Coupled Autonomous Systems

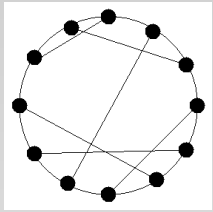
DMR (ITR) 0113049 Gyorgy Korniss (Rensselaer), Mark Novotny (Mississippi State University)

Many of our vital technological, information, and infrastructure systems form a complex network. Examples range from large-scale grid computing networks and the Internet to the electric power-grid. Large fluctuations of the "load" in these networks are typically harmful for stability or scalability reasons (e.g., "traffic jams" in the Internet or cascading failures in the power-grid). It is crucial to understand the effects of the topology (connecting the "nodes" of the network) on the global performance of the system and on the load volatility on the individual elements. Knowing the statistical properties of the extreme fluctuations is of great importance from a system design viewpoint, since failures or delays are triggered by extreme events occurring on the individual nodes.

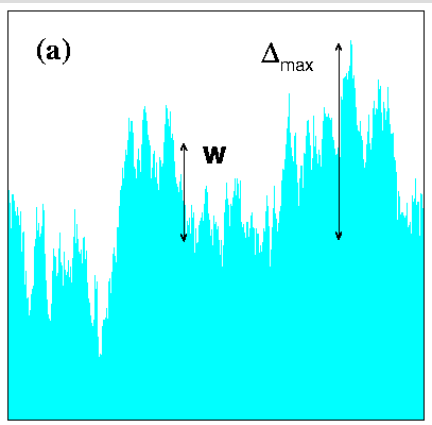
Motivated by the structure of social networks ("*small-world"* effect or "six degrees of separation"), we constructed synchronization schemes for *scalable* parallel simulations capable of tackling large-scale scientific or engineering problems using tens of thousands of processors. Constructing a small-world-like communication topology for the processors, even the largest "load" fluctuations increase *very slowly* (logarithmically) as the total number of processorsh increases. *Phys. Rev. E*, **69** 065104(R) (2004)



regular one-dimensional communication topology



"small-world" topology when random links are added



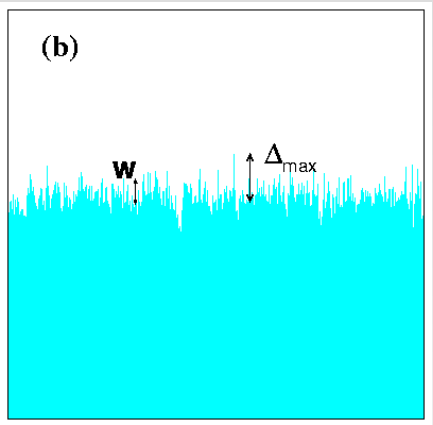


Figure 1. Synchronization landscapes in massively parallel simulations **(a)** When compute nodes only communicate with local neighbors large fluctuations in the local load (progress of the computations) emerge **(b)** When each node is also required to communicate with a randomly chosen one (resembling a *"small-world" network*), *synchronization emerges autonomously*, without a central command. Not only the average (w), but also the largest fluctuations (Δ_{max}) are very small, resulting in a scalable scheme.

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Outreach activities:
'Questar III New Visions program at Rensselaer: G. Korniss developed lectures for local high-school students to introduce them to basic concepts of simulations and modeling (Spring 2002, 2003, 2004). In this program, spanning through the full year, high-school seniors (from around the Albany, NY region) can explore basic concepts in science (and other areas as well), e.g., through guest speakers, mentoring, and a senior project.
Mark Novotny has instituted and runs a "Full Moon Physics Competition", an online competition for Mississippi and local area high-school students.

Educational:
4 undergraduates: Brad McAdam, Joseph Yasi (Rensselaer), Shannon Wheeler, James Nail (MSU); 5 grad students: Hasan Guclu, Balazs Kozma (Rensselaer), Daniel Logue, Poonam Verma,Terrance Dubreus (MSU);
post-doc: Alice Kolakowska (MSU);
pre-college teacher: Tammie Borland (Questar III)

Collaborators:
Zoltán Toroczkai, Matt Hastings (Los Alamos), Zoltán Rácz (Eötvös University, Budapest), Lev Shchur (Landau Inst. For Theoretical Phys., Russia)

Figure 2. (*from left to right:)* Zoltán Toroczkai (senior collaborator), G. Korniss (PI), and Hasan Guclu (graduate student) in front of the Center for NonLinear Studies (CNLS) at the Los Alamos National Laboratory (LANL).

Graduate students Hasan Guclu and Balazs Kozma participated in the Los Alamos Summer Student Program, supported by LANL, in the last three summers. Collaboration and student participation in research at LANL is an integral part of our educational activities. LANL also supported short-term visits of the PIs for collaboration.